LA-UR-21-28414


Title: w19_nubhlight FInal Report

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Intended for: Report

Issued: 2021-08-23

# w19_nubhlight Final Report

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LA-UR-XX-XXXX

## Self Assessment of Scientific and Programmatic Impact

The in-spiral and merger of two neutron stars produces several signals observable on Earth. The in-spiral of two compact objects produces gravitational waves—ripples in spacetime—detectable by the LIGO and VIRGO detectors. The two stars will tidally disrupt each other, throwing off material, some of which escapes and some of which forms a disk of hot nuclear matter accreting onto the central remnant. This accretion drives a pair of powerful ultra-relativistic jets of material along the polar axis. These jets are ultimately responsible for producing short gamma-ray bursts, some of the most brilliant and energetic events in the cosmos.

Accretion also drives a hot, (relatively) neutron-rich quasi-spherical outflow off the disk. This *wind*, along with material unbound during tidal disruption (called *ejecta*), is a site for r-process nucleosynthesis. Heavy elements are formed and their subsequent radioactive decay powers an electromagnetic afterglow that lasts for several weeks. This afterglow is known as a *kilonova* or *macronova*. The color of this afterglow depends heavily on the elements produced during nucleosynthesis. If the material is sufficiently neutron rich, it produces lanthanides, which are opaque to blue optical light, making the kilonova red. If it is less neutron rich, the absence of lanthanides implies that the kilonova may start blue before reddening.

Tidal ejecta always produces a red kilonova. The literature was divided on whether or not a blue kilonova can be produced in the disk wind. In the first year of the `w19_nubhlight` proposal, we resolved this ambiguity. In [1] we presented our code, $\nu$`bhlight` and described the rigorous tests we had performed to ensure scientific correctness. Then, in [2], a multi-disciplinary LANL-based team, led by PI J. Miller, simulated a disk formed after the 2017 neutron star merger and showed that a blue kilonova *can* be produced by disk wind. This helps explain observations in 2017, which showed a kilonova with both red and blue components.

We also investigated a connection between neutron star merger disks and disks formed in so-called “failed supernovae,” also called *collapsars*. We found that, although the physics is quite similar, very few heavy elements are produced in collapsar disks [3]. We also contributed a plot to a review paper [4] on Kilonovae. These works received significant attention and have been high-impact—combined they have received well over 100 citations in the few years since publication, and have resulted in about half a dozen high-profile invited talks.

In the second year, we expanded scope significantly. We performed preliminary calculations of black hole-neutron star mergers, which we expect to result in a high-profile student publication [5]. We also contributed to the analysis of the electromagnetic afterglow of such events [6] and the associated gamma ray burst [7].

We also successfully engaged in related science. The nuclear and neutrino physics of core-collapse supernovae is rather similar to that of collapsars and neutron star mergers. With a (now graduated) PhD student, Sanjana Curtis, we performed a large modeling effort of core collapse supernova light curves [8]. Similarly, the accretion physics of the common-envelope phase of a black hole and a massive star is related to the accretion physics of post-merger disks. Directors' Fellow postdoc Soumi De performed simulations of this scenario with $\nu$`bhlight` and a publication is in preparation [9]. We also engaged with a graduate student, Joanna Piotrowska, on numerical methods research for spectral methods, resulting in another publication [10].

## Publication List


[1] J. M. Miller, B. R. Ryan, and J. C. Dolence, "$\nu$ bhlight: radiation GRMHD for neutrino-driven accretion flows", The Astrophysical Journal Supplement Series **241**, 30 (2019).

[2] J. M. Miller et al., "Full transport model of gw170817-like disk produces a blue kilonova", Phys. Rev. D **100**, 023008 (2019), arXiv:`1905.07477 [astro-ph.HE]`.

[3] J. M. Miller et al., "Full Transport General Relativistic Radiation Magnetohydrodynamics for Nucleosynthesis in Collapsars", ApJ **902**, 66, 66 (2020), arXiv:`1912.03378 [astro-ph.HE]`.

[4] C. L. Fryer et al., "Understanding the engines and progenitors of gamma-ray bursts", European Physical Journal A **55**, 132, 132 (2019), arXiv:`1904.10008 [astro-ph.HE]`.

[5] S. Curtis, J. M. Miller, and C. Frohlich, "Full transport grrmhd for kilonovae from black hole—neutron star merger disks", Submission Planned to ApJ Letters, LA-UR-20-27560 ( In prep. 2021).

[6] W. Even et al., "Composition Effects on Kilonova Spectra and Light Curves. I", ApJ **899**, 24, 24 (2020), arXiv:`1904.13298 [astro-ph.HE]`.

[7] N. M. Lloyd-Ronning et al., "Constraints on gamma-ray burst inner engines in a Blandford-Znajek framework", MNRAS **485**, 203–210 (2019), arXiv:`1902.01974 [astro-ph.HE]`.

[8] S. Curtis et al., "Core-Collapse Supernovae: From Neutrino-Driven 1D Explosions to Light Curves and Spectra", arXiv e-prints, arXiv:2008.05498, arXiv:2008.05498 (2020), arXiv:`2008.05498 [astro-ph.SR]`.

[9] S. De, J. M. Miller, and C. Fryer, "Wind and outflow from the common envelope evolution of a black hole and a massive star", Submission Planned to ApJ ( In prep.).

[10] J. Piotrowska and J. M. Miller, "Spectral shock detection for dynamically developing discontinuities", arXiv e-prints, arXiv:1910.00858, arXiv:1910.00858 (2019), arXiv:`1910.00858 [math.NA]`.


## Financial Impact

- This allocation has supported work performed under the "Nucleosynthetic Probes of Cosmic Explosions" LDRD DR grant. Work using this allocation accounts for about 0.3 FTE's of labor from that project.

- Work performed here helped us seek out additional funding from a CSES rapid response grant for follow-up work on neutron star-black hole mergers. This accounts for about 0.3 FTEs of funding acquired.

- Work performed here led us to seek out an additional IC allocation for follow up work to support the CSES rapid response grant, which we received.

- Directors Fellow postdoc Soumi De utilized this IC allocation for her modeling. This allocation accounted for approximately 0.3 FTEs of labor from that project.

- Gradutate student Joanna Piotrowska, visiting under CNLS fellowship, utilized this allocation. It accounted for approximately 0.1 FTEs of labor for that project.